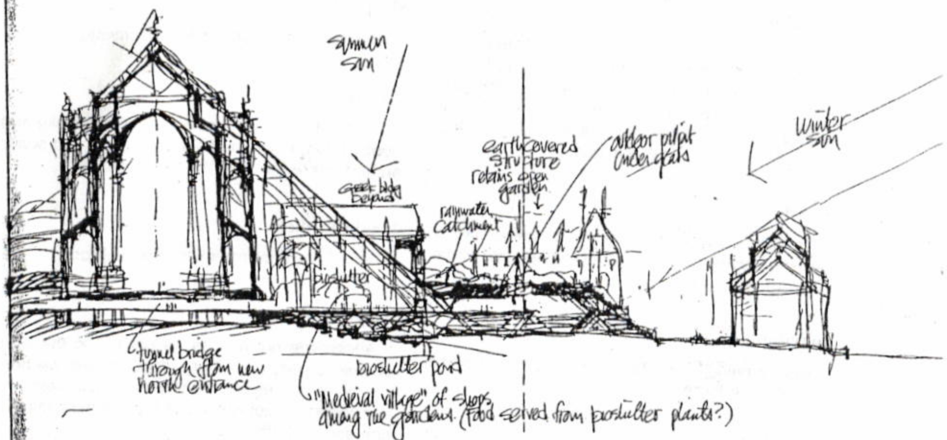


Malcolm Wells

ENERGY and ARCHITECTURE

Solar Village Principles and Construction Ideas

Malcolm Wells

Approaching self-sufficient living through reverence for life, using systems tested by America's experts in soft technology. Food. Land Husbandry. Shelter. Networks. Appropriate Scale. Wastes. Aquaculture. Sharing. Solar and Wind Energy. Privacy. Limits. Conservation. Fun. And Elephants.

Expressive

It must not need explanation. It must say "reverence for life." It must exhibit its dependence on rain, wind, sunlight, earth, and oxygen.

Identifiable

It must say "here we are" without recourse to the use of signs, lights, or arrogance of architecture.

Beautiful

(Unattainable, but always the goal.)

Wild

Over and over, we stumble on the obvious: if the habitat is provided, the wildlife will reappear. Can we afford to set aside ten percent of the land around the village as forever wild? Can we afford not to?

Secure

There may be no refuge from terrorism, but the village must offer shelter from storm and noise, and perhaps from vibration as well.

Consistent

Each village will inevitably develop a direction, an emphasis, at least slightly different from that of all the others. The more clearly the village expresses itself the better the design.

Contoured

Nothing says "husbandry" more directly than does contouring, following the design of the land, not fighting it.

Permanent

If trees and topsoil grow at a hundred-year pace, we can't be tearing up and rebuilding and tearing up again every ten or twenty years. Interiors, occupancies, these can change at will, but let the earth-platforms and the encircling land be at peace, untouched again for generations.

Flexible

Organic, growing and shrinking, responsive to new knowledge, new needs—not locked into whole, perfect forms.

Inevitable

Appropriate, local, right for its time and place. As if it grew there.

Earth-Related

Stable, horizontal, sheltered, permanent.

Continuous

No more dot-dot-dot architecture! No more parts instead of wholes. The village must flow out of the land and through time as well. As if it is growing there.

Linear

The wheeled vehicle, whether it be a pushcart or a self-propelled device, seems to dictate flow-through, as opposed cellular, circular, or stepped-floor spaces. Nonvehicular areas (living units, for instance) can line the linear parts and be delightfully stepped, sloped, and interrupted, but since the village, in order to be successful, must first of all *work*, the ease-of-work aspect, especially when combined with the need for contoured forms, seems to dictate linearness.

Diverse

From Jane Jacobs to the speakers at our conference, all seem to agree that diversity at all levels (occupancy, crops, life support, human insterests) is the key to long-range success.

Simple

Understandable, consistent, geometric.

Exciting

Filled with the unexpected, not with pitfalls and booby traps, but with changes of pace and scale; architecture without all the fun extracted.

World-Linked

Part of the growing information network.

Accessible

Accessible not only to visitors but to the kinds of work crews, machinery, and vehicles we hope will never be needed: emergency equipment, rescue teams, major structural replacement machinery, and so forth.

Educational

Of course. Life processes (and the processes of learning about life) always on display.

Democratic

With a few Republicans thrown in for balance, perhaps.

And what about these? Limits to growth? The use of chemicals and poisons? Private ownership? Private belongings? Inheritance? Existing structures (demolish, salvage, restore, retrofit, preserve?)? Evil? Imports (how much fuel, food, containers and wrappings; how many experts, specialists?)? Village characteristics and rules (how much should be *imposed* in the way of aesthetic controls, diversity, design; and who should do the imposing?)? Domestication vs. wildness of animals? What's the best way to hide the village dump?

More and more, I think a tools/models-book will generate a vast first-generation village-activity all around the world, and from *that* experience, from its successes and failures, will spring the really worthwhile villages we're all talking about. We can begin to lay down all the rules at this time.

8. Land is too important to be an item for speculation. Therefore, some form of land-trust system will be necessary to regulate its use.

An Agricultural Shift

9. Because a safe, sustainable culture must rely on sunshine, almost exclusively, the land will be called upon to be a sustainable and net energy producer for food, clothing, shelter, and transportation.

10. Because seeds are now, and have historically been, a central item in our diets, most alternatives in agriculture must include them. The closest approximation to the former natural vegetation in vegetative structure is a high-seed-yielding perennial polyculture. Therefore, the majority of the acreage would be devoted to this form of agricultural ecosystem.

Technological and Institutional Change

11. Essentially all the technology on the land should be powered from a sustainable energy source near at hand. Direct solar power, windpower, and hydropower should be used when possible.

12. Though machinery may be manufactured in a distant place, most repair should occur at the village level if not on the farm.

Equipment and Support Buildings

Operator-Owned Equipment

One 45 horsepower tractor run on alcohol. One multiple reaper combine (pulled and powered by PTO from tractor). One side-delivery rake. One baler for 1,000–1,200 lb bales. Windmill for pumping water. (Water tank is the accumulator.) Wind-electric power for refrigeration to store food. Freezing condition "accumulates." Wind-electric power with induction motor to put power on line. Ordinary wrenches and small tools.

Village Rental

Easy Flow Fertilizer (phosphorus and calcium) distributor. Chisel (attached to tractor) for breaking sod-bound soils. Annual seedbed-preparation equipment. Miscellaneous small tools and power equipment.

Support Buildings

Machinery and solar-heated tool shed and workshop. One hundred percent solar (passive and active) partially underground house set into bank. Solar and mobile hog and chicken pens.

The 160 Acre Farm

"The Fuel 40"

A six-species polyculture: five grasses, one legume. These seeds are high in carbohydrates, low in protein. The field averages about 20 barrels of crude equivalent per year. Livestock are cycled onto this acreage for a few weeks to enhance crumb structure of soil.

"The Multiple Purpose 40"

A six-species polyculture: four grasses, two legumes. Beef stock turned in for "finishing" on seeds. Some years seeds harvested for cash crop. Early vegetation to methanol still in village with limit of 2–5 barrels of crude equivalent per year. This 40 is "cushion" acreage, often using the poorest land.

"The Cash Grain-Hay 40"

A six-species polyculture: four grasses, one legume, one composite. Fall harvest for cash grain. Livestock pasture June 1–August 15. Hay in windows and large bales after seed harvest. Winter area for hybrid derivative of buffalo-domestic cow.

Windmill

Carry-Over Native Pasture

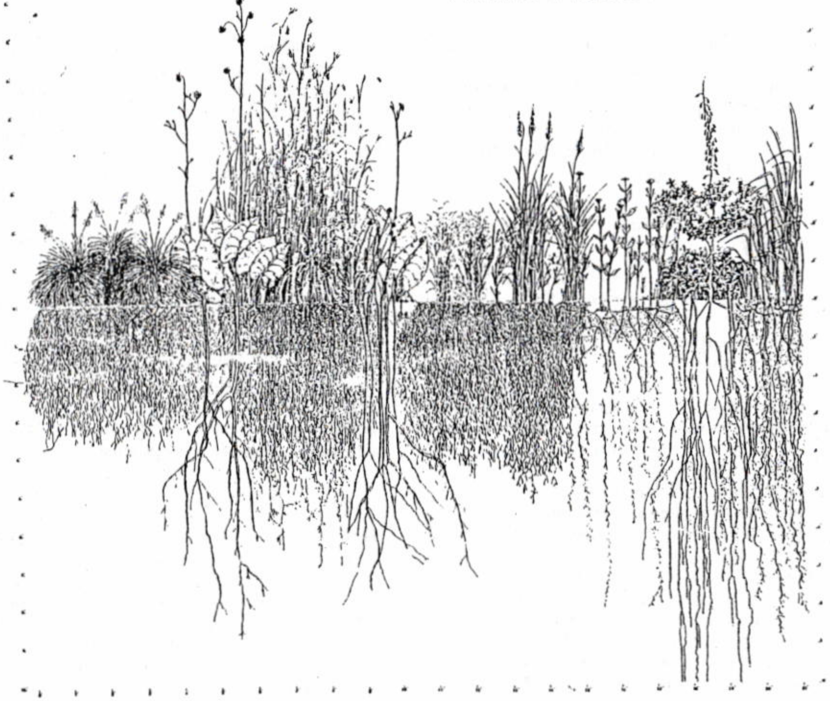
Bottom Land Boundary

Creek bottom for garden and annual cereals (corn, wheat, soybeans, etc.). Managed mixed woodlot. Mixed orchard.

Bottom Land

Workshop, machine, and tool shed. House. Wind-electric machines for four families. Commons.

Prairie Plants



The Sustainable Farm

Wes Jackson

Assumptions

General

1. A viable nearby village and a distant city are necessary supporting elements for a viable farm. *Supporting* is emphasized, for the farm does not exist for the village or the city but rather land is the foremost and most highly protected of any component in the entire support system.

2. Though the farm described here is characteristic of a region of highly specific needs, the principles employed by the New Age farmer would be the same throughout the land, from New England to Southern California.

Religious Considerations

3. For humans, as well as for all species on earth, our planet is the best of all possible worlds. There is no meaningful escape valve for most of us.

4. In the long run, land determines more of the possible patterns of activity on the planet than humans.

5. Land is a community that includes the living and nonliving and is not just dirt.

6. The highest calling of an individual is to participate with the land in the promotion of a healthy and productive biosphere in order to meet, in Thoreau's words, "the expectations of the land." Holistic land stewardship is a way of life.

7. We are to encroach upon wilderness only as "strangers and sojourners." Wilderness is the standard against which we judge our agricultural and cultural practices. Therefore all natural ecosystems are to be protected. Such systems are the most reliable source of information for a sustainable future.

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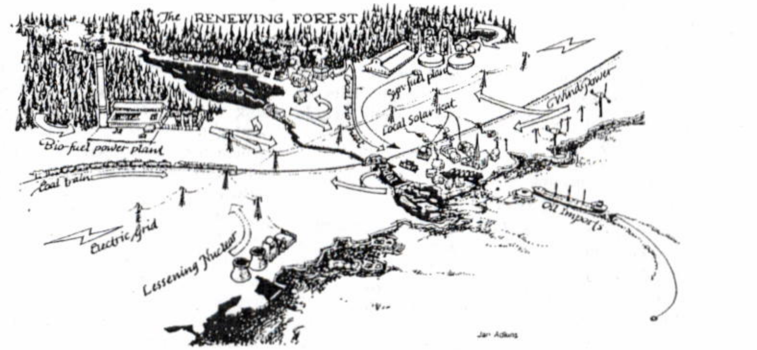


Soft-Energy Paths From Here to the Village

Amory Lovins

In any sustainable human settlement the renewable energies of sun, wind, water, and biofuels suffice to meet all reasonable human needs for energy—provided the energy is used very efficiently. Energy would be harnessed via various commercial technologies from the renewable energies that impinge on the area, and in the case of a city, on its environs. Economic efficiency, engineering elegance, and ecological benignity all seem to lead to the same combination of very efficient use with soft technologies or appropriate renewable sources. Supplying energy at a scale and quality appropriate to the task tends to minimize the economic and social costs of distribution and conversion respectively.[1]

Just what energy technologies make sense is a use-and a site-specific question. What tasks do we want energy for? What forms or qualities of energy will do these tasks most simply and effectively, with the best opportunities for integration and for cascading energy through successively lower-grade tasks? How little energy can we get away with, at what scale of unit use, with what distribution and variation in time and space? How low-tech, reliable, convenient, durable, and resilient do we want our supplies to be? How might these things change in the future or with different people? How precisely do we know these things?

These are the main things we need to know before we start asking what renewable energy flows are available to us and how to harness them. For each site, some forms of energy, or degrees of reliability, or scales of supply are much more easily achieved then others; no site is average or routine. Each needs ideas. Knowing the quirks, we can reexamine how hard we want to work to get the right kinds of energy to do the tasks we started with; maybe we don't really need a steel mill after all.

Important types of energy needed may include heat at low temperatures (say, below the boiling point of water), at medium temperatures (cooking and most other chemistry), and at high temperatures (metallurgy and ceramics); mechanical energy at fixed sites (to run machines) or in vehicles; electricity for the tasks that require this special, costly form of energy (electronics, electrochemistry, arc-welding) and for substitutable tasks (motors that can run instead on compressed air, lights that can run instead on methane, and so forth). Road and air vehicles can generally do with solid fuels (external-combustion engines or gasifiers), electricity stored chemically or in flywheels, the coolness of liquid air, or possibly other methods. The array of energy carriers and conversion devices available to marry a renewable energy form with a task is as rich as your imagination. Most of the things that look as though they ought to work do work, and many of the brightest ideas have come from ordinary people without special technical backgrounds.

[1]Soft technology is the friendliest name for what has also been called alternatiye and, by E. F. Shumacher, appropriate technology. Stewart Brand, the editor of *The Next Whole Earth Catalogue* and the *CoEvolution Quarterly*, has written, "'soft' signifies something that is alive, resilient, adaptive, maybe even lovable." My own favorite description for the kind of technology we're talking about is that it is forgiving. Scale and locale are implied. It is not endlessly consuming of non-renewable resources. A bioshelter, a windmill, small scale farm machinery, a windbreak of trees, wind-driven commercial and passenger sailing ships could qualify as soft technology. Nuclear bombs and nuclear power, the wan Dam, the Four Corners Power Plant, and the private car are not. There are also intimations of sustainability, a possibility of a future in the term. And it is reversible. One can undo it.

N.J.T.

The most obvious soft technologies, each best suited to particular uses in very rough order or decreasing share of typical end-use needs include the following:

Passive solar heating, cooling, and crop drying.

Seasonal storage of ice or warmth from a solar pond.

Active solar heating and cooling (often integrated) at low temperatures (a need for active solar space cooling is a symptom of bad buildings, in any climate).

Active solar heating at medium temperatures, through mirrors (which can be aluminized plastic films), Fresnel lenses, or very selective collectors in a hard vaccum (these can yield 5,000 to 6,000 degrees Celsius under load on a cloudy winter day).

Active solar heating at high temperatures (over 1,000 degrees Celsius); this required high concentration ratios and direct (not diffuse) sunlight, though a low-tech, low-cost solar furnace on the Olympic Peninsula has given an impressive performance running a steam-engine generator.

Burning wood or farm or forestry wastes, taking great care to conserve soil fertility (and possibly adding steps like gasification or densification).

Converting such residues to liquid fuels (mainly alcohols or pyrolysis oils), using pyrolysis, acid or enzymatic hydrolysis, fermentation, and so forth.

Anaerobic digestion of some wet residues, especially those rich in nitrogen.

Windpower to make electricity (with or without grid integration) or hydrogen, directly drive machinery (including water pumps), or compress storable air to run machines.

Existing, or low-head high-volume, or high-head low-volume, or run-of-the-river hydropower, or (in special cases) small-scale wavepower, again for electricity or direct mechanical drive.

Solar ponds operating low-temperature heat engines (this appears to be the cheapest known source of base-load electricity in many climates).

Solar cells (photovoltaics), which may yield medium-temperature heat as a coproduct if they have concentrators—and cheap amorphous cells will almost certainly be here in the next few years before we know what to do with them.

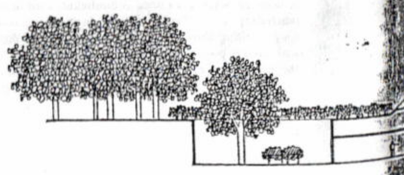
Hybirds of these technologies, such as a photovoltaic coating on a flat-plate solar collector, a bioconversion system driven by solar process heat or stirred by wind-power, a plastic-film solar still/greenhouse, an integrated microhydro/wind/photovoltaic/electrolysis/fuel-cell system, or a small wood-fired co-generation/pyrolysis/district-heating plant.

Hybrids of these technologies (and others, including those we haven't yet thought of) with other processes, including water and nutrient recycling, food production, shelter, and manufacturing. The possible combinations are too numerous for a computer to enumerate in the lifetime of the universe.

Most of these systems are several times cheaper than alternative long-run replacements for dwindling oil and gas, and some are cheaper than oil and gas today if one uses the best present art—which the government has probably never heard of—cleverly built, well run, at the right scale, used efficiently, and done right. It is just as possible, though not as dangerous, to screw up a solar panel as a nuclear reator.

The first, second, and third priority is efficient energy use, far beyond the levels of improvement conventionally discussed. No kind of heating system makes sense if you live in a sieve. No kind of liquid-fuel supply system makes sense if you drive a Brontomobile. The "supply curve" for most soft technologies—measuring the increase in cost, difficulty, or nastiness with increasing volume of supply—rises discontinuously and toward the top, very steeply, leading into hard solar technologies such as monocultural biomass plantations, solar power towers, and solar space satellites (which work better if you lay them on the ground in Seattle).

It is far better to save before the supply runs low, to try to make supply superfluous, and to retrofit one's house—using leak-plugging, heavy insulation (say, R-40 and R-60 ceiling in a cold climate), an airtight vapor barrier, good ventilation through a heat exchanger so that it's heated largely or wholly by people, windows, lights, and appliances. In a new house in our worst climates the net space-heating load and the extra capital cost can both be about zero. Any residual need can be covered by slightly oversizing the solar water heater, or if heating with a greenhouse, putting the water-heating panels inside it to avoid the costs of frost-proofing them. Efficient energy use is synergistic with cheap, effective soft-tech design: a tight house can get better performance from a five-to-ten-times-smaller active solar system, and a simpler one to boot, than can a sieve, because the heating load is tiny and unpeaky, the thermal mass of the house is much amplified by its slow heat loss, and no hea



for houses. Their use in this way would amount to a real tragedy.

Topographic features also need honoring, particularly the tops of ridges where the hills comprise vertical shallow valleys and ridges. Drought-tolerant trees, including the piñon, should be planted on some of the ridges.

Agriculture, Aquaculture, and Agricultural Forestry

The economy of the area would be at least half agricultural. The farmers would live with the other citizens within the villages, not segregated. The village, or perhaps two or three villages each linked to a watershed, would be the hub for all of the people.

Food production would take place in five distinct biological zones. Overall, each of these would help strengthen the others through integration. The zones are (1) bioshelters; (2) the village, which would house fish hatcheries as well; (3) stream outwashes for intensive agriculture; (4) semiarid hillsides for extensive agricultural forestry; and (5) the valley for a mixed agriculture of tree crops, grains, fodder crops, and livestock.

To optimize energy use, materials, machinery, and especially moisture and nutrients, broad planning would be done to see that agriculture was dealt with as a system of interconnected parts. The land would be protected from salting or monocrop abuse. In the extensive agriculture and planting of perennial grains and grasses, drought- and cold-resistant strains would be emphasized following the ideas of Wes Jackson. Livestock breeds better adapted to ecological conditions would be investigated. Livestock would not range freely but would be rotated in order to "tune" the various forage ecosystems.

The Village(s)

The village would borrow a leaf from the book of native American pueblos and cliff cities and from various European cities and towns. Separate and isolated family housing would be stringently avoided. Instead the village would comprise connected and shared structural elements. Housing, bioshelters, schools and institutes, civic and religious centers, commerce, and even manufacturing would be combined into an integrated solar framework. The sun, walls, and materials would be shared and do double or treble duty. The level of crafts of the village would be extremely high, and building would not be rushed. A medieval or sacred attitude toward architecture as an expression of divine of the builders would be artists. Local materials would be used whenever possible.

I believe that bioshelters are going to be the key connective element in the Village of the Sun and in future solar villages. Recently, J. Baldwin and I began designing a 300 foot diameter (1.6 acre) shallow-aspect glass-covered geodesic structure that has 30 partially bermed, protected apartments around its periphery; they open out into a solar courtyard and the land beyond. In this design the bioshelter elegantly provides heating, food, and recreation including swimming for a population of up to 120 people at a cost that may be competitive with standard multiple-family dwellings.

I mention this to point out that bioshelters should not be additions to architecture. They should be central elements in the architecture of villages, for they will help heat and cool the inhabited structures and provide a basis for household and community food production.

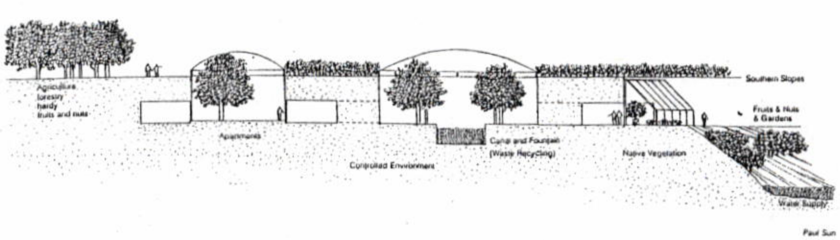
Transportation

Transportation will need careful thought. Agriculture will require special energy-efficient machinery matched to the type of agriculture and the distances traveled. Initially much of this machinery may have to be imported from Europe or the Orient or be manufactured on site. Unlike the people, the equipment would probably be dispersed around the agricultural zones and housed and maintained in energy-efficient underground facilities. On the hillside farms and in the agricultural forests, horses would be used as principal sources of power. Cooperative arrangements between farmers could help minimize amounts of machinery, time in transit, repair and fuel use.

Private cars within the village would be banned. Narrow "back alley" roads would be for service and repair vehicles. The main thoroughfares within the village would be narrow roads for bikes and walking. Old or infirm people could use some form of electric transportation. The village would be linked with the agricultural zones by bike roads and horse paths.

Another alternative, with the least environmental impact, would be a small, fast train that would service the whole ranch and allow agriculturalists, hikers and picnickers, shepherds and cowboys/girls to move back and forth from the village.

Attention to transportation efficiency and to the development of a viable bicycle and horse network would quickly pay for itself in lessened pollution, reduced costs and noise, more pleasurable transportation, and lessened dependency upon petroleum.



Notes on An Agricultural/ Cultural Solar Village in the American Southwest

John Todd

Ownership

In an ideal community, land should not be bought or sold piecemeal. In an ideal village, all land would be held in trust. As a result, there could be no land speculation. Buildings, roads, ponds, mills, barns, trees, houses, housing complexes, bioshelters, and offices could be bought and sold privately between individuals and the land-holding trust or corporation.

A bioregional plan would provide a map for development and determine the limits and relative proportions of activities. The plan would provide building and zoning codes.

The holding corporation would earn its profits from long-term agricultural lease/trust agreements with farmers, through the building, financing, sale, and leasing of the many village components and facilities, and from the leasing of energy-producing rights to private groups within the village and community, or through the direct sale of electricity, water, and other key elements. Sheer diversity of activities would ensure that it would not become a dull or oppressive company town.

Energy

Indigenous energy sources would determine the first set of limits of the scale of activities and the population. Apart from direct solar heating and cooling, I see hydroelectric, solar-thermal-electric, and biofuels from waste recycling as the principal sources of energy. After a certain population had been reached based on per unit or per person energy consumption under this regime, then an increase in population or activity could occur, but only with a concomitant increase in the efficiency of energy use or through further conservation of energy. If per capita energy use were halved, for example, then, in theory at least, the population could double.

Water

In semiarid zones, water is the ultimate arbiter of human activity and density. I would propose that the volume of surface waters, pumped at indefinitely sustainable volumes through turbines and shallow wells, would determine the absolute limit on development. Water would not be imported.

Water use in agriculture and aquaculture as distinct from wasteful spray irrigation would be intensified and given top priority. Gray water and sewage would be purified and recycled within the village. The more times the water can be safely reused in village cycles, the better. Drinking water would be fresh.

Land and Ecosystems

The existing natural biological carrying capacity and ecosystem structure in this region is climate- and water-limited. The region is semiarid with a long, cold winter. As a consequence, the ecology is very fragile. Except for paths, the woods on the hills and valleys reaching into the mountains above the existing settlement should remain untouched for all time. They act as sponges absorbing the otherwise rapid flooding of rain and melting snow. They store moisture for the ground table and protect the area from destructive floods.

Other sacrosanct areas should be the outwashes and the streams lined with cottonwoods. They are the only areas where intensive agriculture can naturally flourish. The outwashes should be saved for agricultural forests, orchards, intensive aquaculture, and for market gardens. I can't overemphasize how precious these lands are. These cot-

distribution system is needed. No official study counts this essential synergism. Integration with food, water, shelter, and materials systems is equally essential.

We must remember that we are seeking not energy for its own sake, but energy services. There are lots of ways to skin an alternator. The objects of transport may be achieved by living where one wants to be, telecommunications, walking, riding a horse or bicycle or scooter or driving a super-efficient car, hitchhiking, taking public transport, airships, or out-of-body trips.

Even on the most barren/dull/cloudy land, there's abundant renewable energy, even wind in the High Arctic winter. The problem is the amount of trouble to get it. One can live better (materially) than the U.S. average on a total energy budget of two kilowatts (thermal), and in the U.S. that's the average rate of insolation on only twelve square meters; so even with collection, conversion, and storage losses, the areas needed aren't unreasonable. Urban densities improve solar economics. But that doesn't mean all forms of energy are equally easy to get at any given site.

For an existing settlement, we need to figure out present and long-term future (post-conservation) structures of end-use needs, to devise a matching soft supply system, then work backward to now to see what has to be built when and what policy instruments will be needed to do it.[1] The only important questions have to do with implementation—what happens in people's heads and how to help it happen from the bottom up by helping people see the energy problem as their problem.

In the long run, energy probably isn't a terribly interesting problem, because we already know conceptually how to solve it, and are starting to do so in practice. If we get out in one piece, then we can get on with some of the really interesting problems: water, soil fertility, food/population, climatic change, ecological resilience, social justice, and peace. In energy, technique is in a sense trivial: full of delights and traps for the techno-twit, but no longer full of deep, scary conceptual gulfs. But using energy to worthy ends, for right livelihood, is profoundly difficult, and is not a technical issue at all.

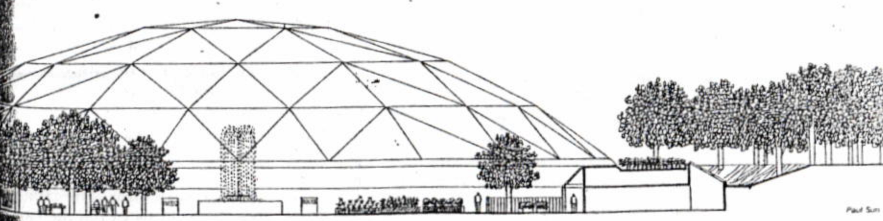
[1]For methods, see *Soft Energy Notes*, May 1979. Available from IPSEP, 124 Spear, San Francisco, CA 94105.

A Dome Bioshelter as a Village Component

J. Baldwin

Serious concern with energy efficiency in buildings requires a standard of performance and reliability rather better than the traditional norm. Many designers, including those aware of the need to conserve resources, do not have the regard for detail necessary to deliver long-term high net energy performance. If we are truly interested in saving energy and materials, we must analyze building design for energy savings in construction, use, and maintenance. Massive amounts of concrete, for instance, mean both a high energy cost in manufacturing the concrete and reinforcing steel, and energy-intensive transportation to the site. Structures that develop leaks due to warp, rot, caulk failure, and ultraviolet deterioration are not going to help society's energy difficulties in the long run. It seems clear that "life-cycle costing" demands a new attitude toward architecture. When the structure is sheltering biological systems, continuing mechanical reliability must be of a very high order lest a component failure result in loss of the cash crop or other function.

One strategy for achieving good performance and reliability is to develop a machine-made structure utilizing high-quality materials in precision components. Not only is quality control thus as-



sured, but the vagaries of construction crews are much less likely to result in poor assembly. Moreover, well-designed industrialized building systems are much faster to erect, thus reducing the critical time between cash outlay and cash return. Speedy installation also reduces the risk of work being interrupted by poor weather conditions, strikes, and inflation. Machine-made systems can also be designed to fit tightly into transport modules such as sea-land containers; parts can be nested and packed in a manner that minimizes transport energy and damage.

A likely candidate for such an architectural system is the geodesic dome. Domes lend themselves well to mass production techniques. Indeed, the reputation of domes for leaking and other weaknesses is almost entirely due to inaccurate preparation and assembly of handmade parts. Domes are also materials-efficient, typically using about 25 percent less material than a conventional structure of similar size. They are well known for easy, rapid erection by inexperienced crews. There are many instances on record of domes as large as 200 feet in diameter being put up in one day. Clever designs do not even require the assistance of an expensive crane.

Domes typically use many parts, but these tend to be of only a few different types. This means relatively low tooling costs and tends to maximize the economic advantages of mass producing a large number of similar items. It also means low inventory and storage costs both for domes awaiting utilization and for repair parts. This reduces both dollar and energy costs associated with stocking. In fact, many dome systems use materials that do not require covered storage, a further saving.

Perhaps the most interesting advantage of the dome is good thermal performance. This advantage arises from the geometry, rather than mechanical devices. Domes have superior surface-to-volume ratios when compared to most other configurations. A relatively low skin area means less skin to lose heat through as well as less skin to buy and maintain. This skin is smooth, offering little resistance to wind. A greatly reduced heat loss due to wind scrub is thus achieved effortlessly; it also imparts an unusually high resistance to weather damage. This, among other reasons, is why domes are used for radar enclosures, especially where weather is violent. The smooth shape has an advantage inside too; natural toroidal convection current patterns eliminate stratification, reducing differences in temperature between top and bottom and the consequent need for circulation fans and/or extra-high heating demands to insure acceptable temperatures at the floor. In the summer these air currents can be used to cool the structure, also without the need for fans. These naturally occurring air motions benefit plants by bringing needed carbon dioxide past them at no fossil fuel cost. Preliminary investigations suggest that control of the aerodynamics of boundary layers inside a dome may result in unusually good insulating effects.

Another benefit of the shape of the dome, which is essentially that of an inverted bowl, is that it can act to reflect radiation back into itself. This is especially important in a greenhouse, where the radiant heat losses can be very high. On the other hand, the dome's spherical section means that sun can penetrate the glazing at a 90 degree angle somewhere on the surface during the entire day. This reduces losses in the morning and evening, when the flat surface of a conventional structure reflects a significant percentage of the available sunlight. This holds true regardless of season. Domes tend to be self-snow-shedding too.

There are advantages to a circular floor plan in a greenhouse: a central mast can support a boom carrying irrigation nozzles and platforms from which the plants can be cared for and harvested without the necessity for space-wasting aisles (typically 20 percent of the floor area). Such a mast could also be used to speed erection of the dome's framework as well as aiding the pouring of the foundation. Circular concrete form-work is also much easier and cheaper, as it can be braced with tension bands instead of many stakes and woodwork. The boom could also ease window washing and other maintenance. Fish feeding could be accomplished from the boom as could tank filling and draining, harvesting, and cleaning. Such a boom could be very simple in concept and execution, in contrast to complex apparatus necessary in other floor plans.

Assuming that the advantages of the dome are now apparent, what other possibilities exist for these structures? One is the potential for very large domes. Buckminster Fuller has proposed domes up to three miles in diameter; his suggestion for covering downtown Manhattan is one such proposal. Bucky estimated this dome would quickly pay for itself in snow-removal savings alone, not to mention the greatly reduced heat and air-conditioning loads that result when the "fin area" of hundreds of buildings is effectively reduced by having the membrane buffer the ambient weather. Such large structures have not been built, though there may be no technical reason why they cannot be. However, smaller structures usually seem to be much less threatening to many people and would be a good way to test such ideas. The capital outlay for smaller domes would be within the capabilities of groups of people; neighborhoods, even small towns or villages might be protected by a dome shelter with the inhabitants living in the perimeter

ing overlooking the central shared space. Such a scheme would be ideally suited to the community-sized seasonal heat storage suggested by Ted Taylor. Consider a sample dome 300 feet in diameter. That gives us about 1.6 acres of climate-controlled space. If housing were in a raised berm around the perimeter and the housing units had a 30 foot frontage inside and outside the dome, there would be space for 30 homes—perhaps 120 people. A 1.6 acre bioshelter could supply them with all their food—except perhaps Twinkies—with a substantial cash crop left over. Hydroponics is another possibility. The synergistic interactions of a tuned bioshelter/Ark would be visible to the occupants. The maintenance of it would be divided. Thirty families is getting near the critical mass necessary for efficient methane production and could be served by a wind generator in the 50–100 kilowatt range, a size that has in itself advantages of being suitable for mass production and distribution. Load management reducing peaks and waste could result in very high performance and excellent efficiency, assuming that the machinery is built to last. This could be rather easily accomplished in such a compact "neighborhood structure."

High-quality hardware would be capital intensive, but it is absolutely necessary for reliability and long-term energy economy. There are several ways that the initial outlay could be managed. First, a cash crop could be used to make much higher mortgage payments than is usual. Second, running costs of such a structure, including the dwellings, should be very low. And third, food costs for occupants would be much less than store-bought food, which carries high costs of transport, packaging (and disposal of packaging), middleman costs and the expense of fertilizers and pesticides. It might also be feasible to rent such structures through an arrangement comparable to the telephone rental system. This would ensure that the quality of the structure would not need to be compromised in order to meet first-cost market price competition. Such a compromise would reduce system reliability, just as low-quality telephone handsets would reduce the reliability of the Bell System. (If you don't think that this can be a serious matter, you must not have lived where the phone system isn't by Bell.) Competition in hardware marketing always results in the lowest common denominator being adopted as industry standard. It might be realistic for banks to amend mortgage policies to accommodate bioshelters, since high-quality, high-performance domes would only appreciate in value while maintaining reliability over many more years than is "normal." The average commercial building, including downtown skyscrapers, in the United States is torn down after 37 years. A properly designed dome could be disassembled and moved easily and without damage, except to the current crop. This could be yet another advantage, as the structures would then never wear out or have to be torn down and would make communities resistant to economic disaster arising from being located in increasingly undesirable locations, which is common. (One could conceive of a used-Ark market!)

Our proposed 300 foot dome community would be a true neighborhood. A good many bits of shared hardware besides the dome itself and the power system and sewage treatment would act as social cement. Shared workshops, recreation space, and laundry facilities would further reduce family expenditures and increase social interaction. Freezer space and facilities for repair and maintenance could be common. The 30 families could share a huge tape library, much larger than any single family could afford. Heavy transport such as Dodge vans could serve as mass transit at this scale with shared costs far less than those resulting from individual daily car use. Recent studies show typical cost of owning a Big American Car to be 38 cents per mile. Perhaps the families could support a modest fleet of identical economical cars to reduce maintenance costs.

The neighborhood dome idea offers the exciting potential of several such domes interacting with one another and the rest of the world in a way that would reduce transportation needs as well as strengthening a regional cooperation in larger enterprises including field farming and forest management. The domes could raise seed stocks, tree seedlings, cover crops for erosion control, and specialty crops such as herbs. They would permit an acceptable high-density housing without creeping "slurb." Properly spaced, a group could be serviced by electric vehicles using power generated by the domes. There is some evidence that domes greatly accelerate air movements in a way that is advantageous to wind generators.

It should be emphasized that the most desirable size for such proposed domes has not yet been determined. To do so would require an examination of economics including mortgage policy and payback periods, requirements of the housing systems, people's needs and demands, structural integrity, codes, fire safety, net energetics of specific systems, implications of materials supply with respect to pollution and other environmental degradation, politics, quality control, environmental effects of the Arks and of accretions thereof, transportation effects to avoid creating commuter communities, and various sociological aspects. What does seem clear is that a neighborhood-sized bioshelter/dome could be the basis for a community that really does tread lightly on the earth.